



## Research Paper

## Influence of rotary disk configurations on droplets characteristics in molten slag granulation for waste heat recovery

Hao Peng<sup>a,\*</sup>, Xuekun Shan<sup>a</sup>, Jingqi Kang<sup>a</sup>, Xiang Ling<sup>a,\*</sup>, Dongxiang Wang<sup>a,b</sup><sup>a</sup> Jiangsu Key Laboratory of Process Enhancement and New Energy Equipment Technology, School of Mechanical and Power Engineering, Nanjing Tech University, No. 30 Pu Zhu South Road, Nanjing 211816, PR China<sup>b</sup> School of Mechanical Engineering, Jiangnan University, No. 1800 Li Hu Road, Wuxi 214122, PR China

## HIGHLIGHTS

- The influence of disk configurations on droplets characteristics is investigated.
- The droplets size, droplets size distributions, filament mass fraction and particle uniformity were analyzed.
- A correlation of  $d_m$  for four types of disks is presented.
- The majority of the droplets size is populated in the range of 0.2–1.0 mm.
- The flat/arc-edge disks represent a superior uniformity compared with the other disks.

## ARTICLE INFO

## Keywords:

Rotary disk  
Disk configuration  
Droplets size  
Filament mass fraction  
Particle uniformity

## ABSTRACT

The influence of rotary disk configurations on droplets characteristics in molten slag ligament granulation was investigated by using the high-speed camera visualized system. Rosin/Paraffin mixture was adopted as the analogue of the molten slag according to the similarity theory. Four groups of disks with different configurations were studied. The droplets characteristics, such as droplets size, droplets size distributions, filament mass fraction and particle uniformity were analyzed. Generally, the droplets mean diameters ( $d_m$ ) decreases by increasing the rotary speed ( $\omega$ ) or disk diameter ( $D$ ), and increases slightly by increasing the liquid flow rate ( $Q$ ). Based on the experimental data, a simple correlation of  $d_m$  for four types of disks is presented. The majority of the droplets size is populated in the range of 0.2–1.0 mm for all  $\omega$  and  $Q$ , which accounts for over 70% mass fraction. The  $\omega$  has significant influence on droplets size distribution and particle uniformity. The flat/arc-edge disk configurations can contribute to produce the narrower size range of droplets and obtain the superior particle uniformity compared to the other two types of disks. In the ligament breakup mode, the filament mass fraction reduces by increasing  $Q$  or decreasing  $\omega$ . Meanwhile, the liquid film breakup mode also has significant impact on the formation of filament.

## 1. Introduction

Molten slag is one of the main products in the iron and steel industries. In 2016, the total amount of 242 million tones molten slag is generated in China [1]. The molten slag discharges at the temperature of 1450–1550 °C and carries a substantial high quality waste heat energy amounting to about  $4.35 \times 10^8$  GJ (14.8 million tons standard coal). Traditionally, the slag is granulated by water quenching (wet granulation) which can recycle slag material by producing the high quality cement with the glassy content exceeding 98% [2–5]. However, this method has several defects, such as high temperature heat energy wasting, large amount water consuming, not environment friendly (pollutants emission).

To fix the above problem, the dry granulation method is proposed in recent years, and it is regarded as the most promising method for heat recovery and material recycle from molten slag [6–8]. Pickering et al. [9] presented the first molten slag centrifugal granulating experiments and obtained the particles with the average diameter of 2 mm. These particles were cooled by the air very fast and reached a glassy content of 95%.

A typical molten slag granulation process includes three steps. Liquid molten slag is firstly poured into a rotary atomizer (disk/cup/cylinder), then centrifugal force acts to stretch the liquid film outwards at the disk rim. Finally, droplets are generated and solidified by the cooling medium (air or Nitrogen). The heat recovered from the molten

\* Corresponding authors.

E-mail addresses: [pshight1@hotmail.com](mailto:pshight1@hotmail.com) (H. Peng), [xliling@njtech.edu.cn](mailto:xliling@njtech.edu.cn) (X. Ling).

**Nomenclature**

|          |                                |
|----------|--------------------------------|
| $D$      | disk diameter [m]              |
| $d_L$    | ligament diameter [m]          |
| $d_m$    | droplets mean diameters [m]    |
| $H$      | liquid film thickness [m]      |
| $L$      | critical length [m]            |
| $l^*$    | ligament length [m]            |
| $N$      | number of samples              |
| $Oh$     | Ohnesorge number               |
| $Q$      | volume flow rate [mL/s]        |
| $Q_R$    | dimensionless volume flow rate |
| $R$      | disk radius [m]                |
| $Re$     | Reynolds number                |
| $R_{Lg}$ | long radius [m]                |
| $R_{St}$ | short radius [m]               |
| $R^2$    | correlation coefficient        |
| $St$     | Stanton number                 |
| $t$      | time [ms]                      |
| $S$      | sample standard deviation      |
| $We$     | Weber number                   |

**Acronyms**

RP mixture Rosin/Paraffin mixture

**Greek symbols**

|           |                                  |
|-----------|----------------------------------|
| $\zeta$   | mass fraction of each size range |
| $\omega$  | rotary speed [rad/s]             |
| $\rho$    | density [kg/m <sup>3</sup> ]     |
| $\sigma$  | surface tension [N/m]            |
| $\mu$     | dynamic viscosity [Pa·s]         |
| $\lambda$ | capillary wavelength [m]         |

**Subscripts**

|   |          |
|---|----------|
| L | ligament |
| l | liquid   |
| m | mean     |
| s | solid    |

slag can be utilized as thermal energy for power or steam generation, or be stored in thermal energy storage system such as compressed/liquid air energy storage system [10–12], thermochemical energy storage system [13], etc.

In order to obtain the high quality and additional-value cement raw material, droplets cooling rate and droplets characteristics (size, size/mass fraction, etc) are the two dominating factors in molten slag granulation. Droplets cooling rates are easily governed by the cooling medium mass flow rate, however, the droplets characteristics are determined by the operational conditions, physical properties, etc, which has drew much attention of many researchers.

Generally, three types of atomizers (cylinders, cups and disks) are common used in molten slag granulation. For rotary cylinder, Kashiwaya et al. [14,15] developed two types of rotary cylinders for molten slag granulation and obtained the correlations between the droplet diameters and the conditions of slag spouting. They found that the minimum diameter of the slag particle was from 10% to 50% of the nozzle diameter. The rotary cylinder can produce more precise sizes of particles with high sphericity. However, it needs more complex system design. For example, the nozzle size should match well with the slag flow rate to prevent the blockage.

For the widely used rotary cup and disk molten slag granulation, Mizuochi et al. [16,17] performed the molten slag dry granulation by rotary cup atomizer, in which the effect of the cup configurations, rotary speed, slag viscosity and gas flow rate on slag droplet size was analyzed. It was found that the smaller slag with diameter less than 1 mm was obtained at the rotary speed of ~3000 rpm, and semi-empirical correlations for the diameters of slag particles were derived. Liu et al. [18,19] presented the experimental investigation on rotary cup granulation with various metallurgical slags. The particle diameter and size distribution of slag with different physical properties were discussed. The results indicated that the mean diameter of solid particles is almost the same with an increase in rotary speed for low viscosity and surface tension slag granulation. The correlations obtained from the experiments could well predict the mean diameter of solid particles for different kinds of metallurgical slags. Xie et al. [20,21] demonstrated a laboratory scale prototype pilot plant for rotary disk granulation using industrial slag from ferrous and base metal industries. The slag size distribution was characterized by twin peaks at 0.4 mm and 1.4 mm, respectively. More than 90% of the granules were smaller than 1.5 mm. These dry granulated slags were found to have high glass content (~99%) and good cementitious properties suitable for cement

manufacture. Most recently, our team [22] carried out the high-temperature experimental works on the rotary disk granulation by using aluminum slag as the medium. Analysis showed that the mean size of particles increased by increasing the feed rate and cooling air rate or decreasing the rotary speed, also the sphericity of particle was primary affected by the rotary speed and the oxide film formed on particle surface. Meanwhile, a correlation for predicting the particle diameter was determined within the relative error of  $\pm 11\%$ .

It is evident that few experiments were performed for molten slag rotary granulation due to the extremely high melting point and complex compositions of various slags. Therefore, plenty of analogue experiments were conducted by using water, water/glycerol mixture, oil, rosin/paraffin mixture, etc as the analogue of the molten slag according to the similarity theory. Liu et al. [23,24] did the cold experiments on rotary cup granulation with glycerol/water mixture as the substitution for molten slag. The results showed that the rotary cup with an inner depth of 30 mm was optimal for granulation and a high-precision correlation describing the relationship between droplets diameter and various factors was established. Zhu's group [25–27] performed the analogue experiments on dry granulation by rotary cups, and the rosin/paraffin mixture was adopted as the analogue of blast furnace slag. The influences of rotary speed, liquid and air flow rates and cup configuration on droplets characteristics were investigated. It was found that the outer angle and depth of cups had significant influence on the droplet diameter, and the cup with outer angle of 90° was capable of producing smaller droplets within the size range of 0.5–1 mm. On the basis of the impact-extent analysis, a modified correlation considering the structural parameters was expressed to predict the droplets size with a confident level of 90%.

Min et al. [28] developed a physical model for molten slag granulation by rotary disk with rosin/paraffin mixture as working fluid. The effects of disk diameter, rotary speed and liquid flow rate on droplet size were discussed. They presented a modified Kitamura equation which can predict the droplet size more precise according to the experimental data. Dhirhi et al. [29] studied the effectiveness of rotary disk slag granulation by using rosin/paraffin mixture as well. The effects of operational parameters such as disk diameter, rotary speed, etc were discussed. Analysis showed that the average droplets diameter increased by increasing the liquid flow rate or decreasing the rotary speed and disk diameter. A correlation for predicting the droplets size with an RMS error of  $\pm 6.1\%$  was developed. A series cold experimental works were also conducted by our team to investigate the droplets characteristics of rotary disk granulation [30]. The results indicated that the droplets size decreased by increasing

Download English Version:

<https://daneshyari.com/en/article/7045716>

Download Persian Version:

<https://daneshyari.com/article/7045716>

[Daneshyari.com](https://daneshyari.com)